THE NATURE OF RESEARCH

MOST RESEARCHERS ARE EXPLORERS SEEKING TO UNDERSTAND WHAT NO ONE ELSE HAS UNCOVERED BEFORE.

What *really* is research? What do scientists *actually do*? What are their *frustrations* and *satisfactions*? This issue of *Connecting with Cornell* (CWC) provides personal answers to these broad questions through conversations that CWC editor Ernestina Snead had in the summer of 2005 with a few of Cornell's most influential scholars. These discussions also indicate some attributes of successful researchers.

Five Cornell professors in diverse research areas describe the intellectual challenges and also the sheer fun that they have had so far in their research careers. Steven D. Tanksley, the Liberty Hyde Bailey Professor of Plant Breeding and Genetics, tells about his studies of the evolutionary history of the common tomato and how he cannot "imagine wanting to do anything else in my entire life." Steven W. Squyres, the Goldwin Smith Professor of Astronomy, talks about the excitement of leading the Mars Exploration Rovers, exclaiming, "Nothing is going to top this!" Barbara A. Baird, professor of Chemistry and Chemical Biology, when recounting her experience of investigating molecular signals in cells, remarks, "I'm just happy thinking about these things … My hobby is science." Shahin Rafii, a Howard Hughes Medical Institute investigator and director of the Ansary Stem Cell Center for Regenerative Medicine at the Cornell Weill Medical College, when acknowledging the long-term value of his insights as a hematologist/oncologist in understanding blood cancers, realizes "that I have made a big difference." Perhaps influenced by his family's seal, "To experiment is the true way," Watt W. Webb, the Samuel B. Eckert Professor of Applied and Engineering Physics, recalls his continuing quest to see inside cells and, at age 78, describes the many projects that he intends to finish before retirement.

One academic may swirl a beaker of exotic microbes and chemicals while another steers a Mars Exploration Rover across the desolate Martian terrain, but all believe, like Baird, that research is simply "trying to figure out how things work." To these scientists, research is like a fascinating game that is great fun to play. Tanksley mentions "how interesting it is trying to understand problems and putting the pieces together like a puzzle." The process involves knowing the basic rules, recalling past facts, and seeking more evidence. Squyres remarks that each researcher is a "detective at the scene of a crime looking for the clues" that nature freely—but maybe not so readily—provides when the correct questions are asked and the appropriate facilities are available. Sometimes previous experiments by other scientists may have already provided the sought-for answers, but a researcher must be aware of these results and trust them. If the "alleged facts … seem to be nonsense," they may be, notes Webb; alternatively, another researcher may not understand the results. In some subjects, like high-energy physics, researchers watch a game played before them, and their task as researchers is to deduce the contest's rules, learning how things operate so that the principles can be extrapolated to new situations. By contrast, in observational sciences like astronomy or geology, researchers are presented with the contest's outcome, from which they must try to derive the rules (or break the code). Knowing how the universe has evolved, these scientists seek ultimately to infer the starting conditions that lead to the world in which we live today. Over the last half century, the science of biology has, at an accelerating pace, moved away from mere cataloging to studying processes with the most modern tools of the physical sciences and technology. Current wisdom is that the majority of this generation's scientific breakthroughs will happen in the life sciences.

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Many scientists are driven by curiosity and others by the order and beauty they see in the universe—some peering through a microscope and others through a telescope. Whether translating medieval manuscripts or transposing monster matrices, most researchers are explorers seeking to understand what no one else has uncovered before. Squyres, who roams Mars with his rovers, is an obvious example. He admits that "going some place that no one has ever been before turns me on! Another thing … is seeing some [vista] that no human eyes have ever seen before." Scientists recognize that they are confronting the unknown. "Science is discovery," for Tanksley. He marvels, "I never know what's going to happen here in the laboratory … what research problems will arise."

What are some keys to the research successes of these scientists?

Unlike Mary Wollstonecraft Shelley's Dr. Frankenstein, today's scientist is not a lonely pursuer of truth. Rarely is research accomplished by a solitary scholar toiling in an isolated ivory tower. Research, instead, is a social endeavor filled with human cooperation and conflict. Personalities, friendship, and rivalry play roles in what research is done and who does it. Sacrifice and envy occur as often in laboratories as they do in boardrooms. Fads and styles may influence the topics that will be studied.

All five scientists value learning from others. Much of today's most successful research crosses disciplinary boundaries. Partly owing to Cornell's revolutionary graduate field structure, interdisciplinary study is an area in which our university has achieved an enviable reputation. As Squyres points out, the involvement of colleagues from other disciplines is vital since the topics are multidisciplinary. "No one person could possibly have all the knowledge necessary," he says. "[Research] is a team sport." Rafii describes how talking to his colleagues and students is crucial to brainstorming: "We connect a few lines and a new idea is born." More than 50 years ago, Webb chose Cornell because it went far beyond other institutions in accommodating flexibility and encouraging research across disciplines.

The flashy brochures that market top universities to high school seniors usually claim that academic research benefits undergraduates by making the faculty's teaching relevant and up-to-date. This is true. In addition, however, as the distinguished faculty highlighted in this CWC acknowledge, teaching stimulates their research. The necessity of simplifying complex subjects in order to explain an idea to undergraduates requires distilling concepts down to their essence. Baird points out that lecture preparation provides an opportunity to reexamine the foundations of one's subjects, as well as the basis for one's professional beliefs. Any teacher knows too well that inexperienced but intelligent undergraduates are often impertinent enough to ask fundamental questions. They do not know enough to realize that their "most incredibly unsophisticated" questions were put to rest long ago, often relying on assumptions that are forgotten and perhaps now known to be incorrect. Rafii says that sometimes following a student's naive question, he realizes, "Aha! That might be the right question to ask." It is a truism that faculty are privileged to associate with students.

Anyone who has experienced the thrill of scientific discovery will relate to Squyres' exultation, "Hold everything! We've found something totally new; we're going to change our plans completely." Such moments are especially fulfilling when they can be shared with colleagues—particularly beginning students, who otherwise might believe that everything is already known and can be found in the course textbook. Most scientists agree with Tanksley and Squyres that researchers have an obligation to share the adventure with those who are footing the bill.

Social responsibility motivates many researchers. Several here speak passionately about how their research will ultimately improve the human condition by defeating cancer or other life-threatening diseases, by easing allergic reactions, or by expanding the world's food supply and augmenting its nutritional value. Tanksley feels that he has a "great responsibility to provide for the next generations." Squyres worries about spending the public's funds wisely, but also describes his awe when addressing cosmic questions. His sense of wonder recalls the 1969 congressional testimony of Robert R. Wilson, the late Cornell physicist, who advocated using federal funds to probe subatomic secrets and to support the public arts; he argued that such projects enrich the human spirit and provide a reason for defending our society.

What are some keys to the research successes of these scientists? Obvious ones are native talent, training, diligence, and drive. Equally critical is the ability to identify major research questions in one's field that can be solved at this time with the available tools. Once such topics have been identified, a scientist must be able to jump quickly across disciplines. This requires a broad background that enables access to newly appealing research areas and the mental flexibility to switch paradigms. While sorting through experimental data or observational results, a researcher must be able to identify that odd piece of information

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that demonstrates past approaches are incomplete or wrong. The public sometimes wonders if luck has a role in scientists' accomplishments. "Lucky" insights or seeing new connections come to those who have prepared fertile soil. Rafii expresses this with the appealing phrase, "serendipity with watchful eyes." It may also be that knowing a crucial question should be asked is the key. Bernard Baruch once mused that many before Newton watched apples fall, but it was only Sir Isaac who asked why.

Every experienced researcher knows the pivotal place of intuition when approaching problems—how an as-yet-unproven solution can just "smell right." But the seasoned veteran is also aware of how easily each of us can be misled. At Caltech's commencement 30 years ago, Richard Feynman cautioned, "You must not fool yourself … and you are the easiest person for you to fool."

Successful researchers usually have both pride and humility. When working in their established fields, they must be self-confident to pursue their own ideas or approaches. To change research direction, especially when one is comfortable and successful in another venture, requires a faith in one's own abilities, and this is a struggle for many. Humility is equally valuable if a researcher is to trust published results in the classical literature. Humility is also required to accept that something is amiss in one's ideas or wrong with one's data.

What support and policies must our institutions provide for researchers? All researchers need the confidence of their institutions, supervisors, and colleagues in order to move into uncharted waters. The proper instruments and infrastructure, usually provided by external funding and university endowments, are obviously critical to experimental scientists. The challenge is to avoid the entitlement of the already privileged; difficult choices need to be made at federal agencies and on campus for funding to be allocated in fair yet effective ways. Beyond the physical necessities, intellectual and emotional encouragement from colleagues is vital. This is the important intangible of institutional culture that must be nurtured.

I encourage you to ponder these conversations carefully and to recommend them to the next generation of researchers. You will learn much about research and those who do it, just as I did.

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